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THE NINETY-SIXTH STREET POWER STATION OF THE METROPOLITAN STREET RAILWAY COMPANY, OF NEW YORK CITY.

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PRESENTED SEPTEMBER 19TH, 1900.

WITH DISCUSSION.

The events which led up to the building of the new power station of the Metropolitan Street Railway Company were brought about largely by the steady growth of the company.

In 1891 it was decided to adopt mechanical traction for Broadway, and the cable was selected as offering the best tractive power for heavy loads. As the company increased in size, cable extensions were built on Lexington and Columbus Avenues. Having built these, and having laid out other proposed roads, it was seen that the cable, by its multiplicity of sheave pits, curve pits and power houses, was too expensive and cumbersome to be adopted for a large system; and, as the overhead trolley, which had proven so satisfactory in other cities, was prohibited on Manhattan Island, the company began a search for some other system which would prove satisfactory in operation and which would also overcome the objectionable features of both the foregoing systems.

After a careful study of all the underground conduit roads in existence at that time it was decided to build and equip several miles of conduit electric road, experimentally; making the road-bed so that it could be easily changed to a cable road if the experiment failed. This experimental line was built in 1895, and proved so satisfactory that it was decided to adopt the conduit electric trolley as a standard for all main lines. The company now operates all the lines in the Boroughs of Manhattan and The Bronx. Each year, since 1897, it has converted several roads into the conduit electric construction, and when the conversion of the present cable roads is completed, nearly all the main lines will be of this type. All the street railroads in The Bronx are of the overhead-trolley type. The cross-town lines down town are as yet unequipped, because the underground trolley does not seem to be suitable, and the company is still conducting experiments with a view to securing a motive power for them.

Location.—The station is located on First Avenue between Ninety-fifth and Ninety-sixth Streets, and the property extends to the East River. The dimensions of the building are shown on the plan, Fig. 1. Provision has been made for a marginal street along the river front, by leaving a space about 75 ft. wide between the building and the river, in case the Dock Department should ever conclude to condemn and purchase that strip.

The engine house is on the north and the boiler house on the south side of the building. The width of the former is about 112 ft., and of the latter about 88 ft. The chimney is near the center of the boiler room. Fig. 2 is a longitudinal section of the boiler house, Fig. 3 a longitudinal section of the engine room, and Fig. 4 a cross-section through the building.

The space opposite the chimney, in the center of the boiler house, is utilized as follows: In the basement this space contains the water supply piping; on the first floor it contains the feed pumps; the second and third floors are left for secondary heaters; the fourth is for an oil room, and the fifth is used as a machine shop for light repairs. An elevator and a stairway provide access to each floor.

On each of the first, second and third floors space is provided for two large blowers to be used for forced draft if it be found advisable or necessary to force the boilers.

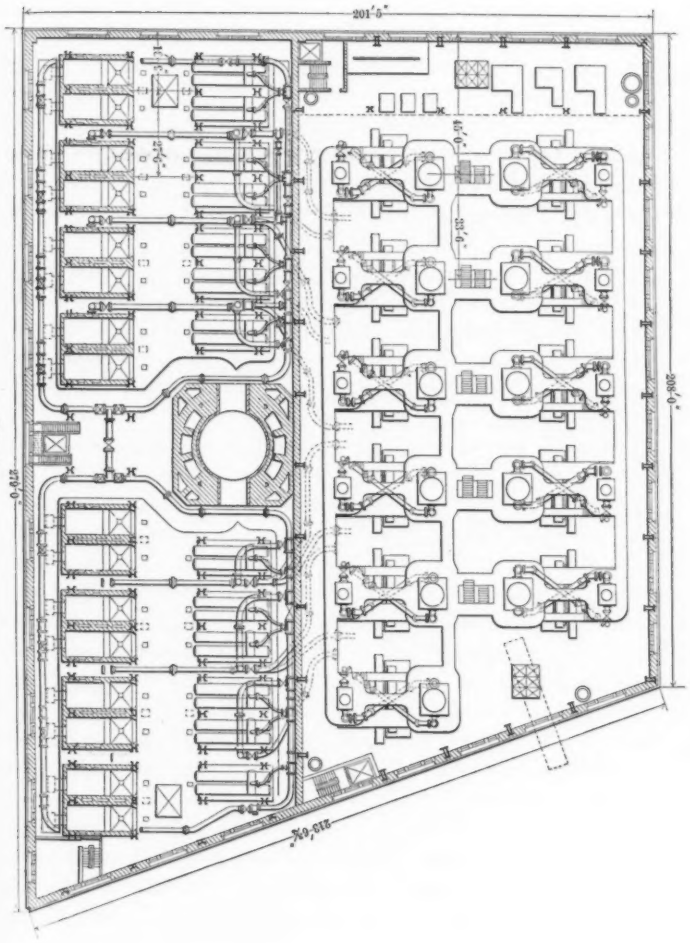


FIG. 1.

At the southeast corner there is a space divided up into a stairway well and a wash room on each boiler house floor for the men. Over each wash room there is a mezzanine floor for lockers, etc.

The Foundations.—Piles were driven over the whole site and then a thick bed of concrete was put in. The thickness of the concrete under the chimney is 20 ft.; under the center of the boiler house it is 7 ft., and under the remainder of the building 5 ft. The piles are from 35 to 40 ft. long, and extend up into the concrete 1 ft. Those under the chimney are 45 ft. long. The piles were not driven entirely to refusal, yet they are firmly embedded in the coarse sand or gravel, and, according to the *Engineering News* formula, they have a sufficient bearing power.

Near the present westerly property line of the site there was an old bulkhead crib, and old cribs extended out along Ninety-fifth and Ninety-sixth Streets, formerly making piers near these streets. The site of the building was formerly the water slip, and therefore the upper part of the excavation was mostly filled material of comparatively recent date.

The cribs extend down near each street line, and are part way under the building. It was found that, by removing the tops of these cribs, when the excavation was being made, it was possible to drive piles somewhat regularly and sufficiently well through the bottom part. Some of the piles were shod. The cribs did not extend under the area occupied by the chimney. The preliminary borings indicated that the space between the cribs was filled with heterogeneous matter down to about Elevation — 15. Under this, and down to about Elevation —75, there were beds of sand, each about 10 ft. in thickness, and growing coarser and more like hardpan as the depth increased. The strata below the cribs seem to be almost level over the whole site. Below Elevation —75 stiff blue clay extends down indefinitely as far as known. The piles were driven on nearly 3-ft. centers under the walls, and on 30-in. centers under the center of the building. Under the chimney they were driven a little closer, being placed so that the triangle formed by each three adjacent piles has 30 ins. on a side. The elevation of the former surface of the ground was from + 6 to + 7 ft. The elevation of the basement is zero.

A vault has been built under the sidewalk on Ninety-fifth Street and on First Avenue, with the floor at Elevation — 2. This will be used for

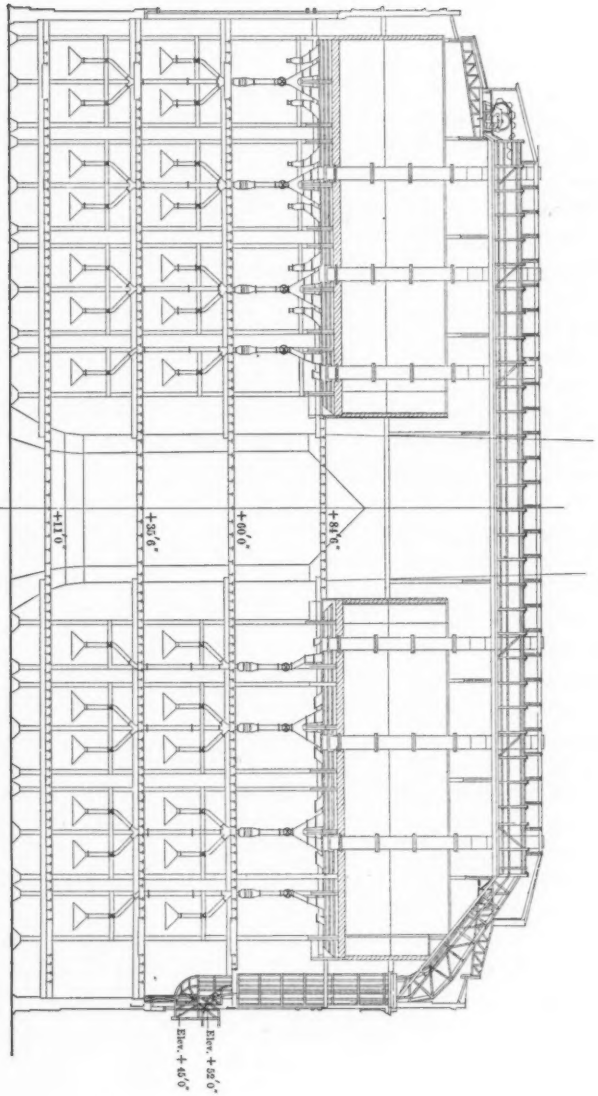


FIG. 2.

the distribution of feeder wires and probably for a small storage battery. There is piling under the wall, and a thick bed of concrete for the floor, which is not piled.

The engine foundations are shown in Fig. 2, Plate XI. They are mostly of brick, but the lower part, below the holding-down bolts, consists of a shell of brick filled in with concrete. Each of the large foundations would contain about 500 000 brick if entirely built of them.

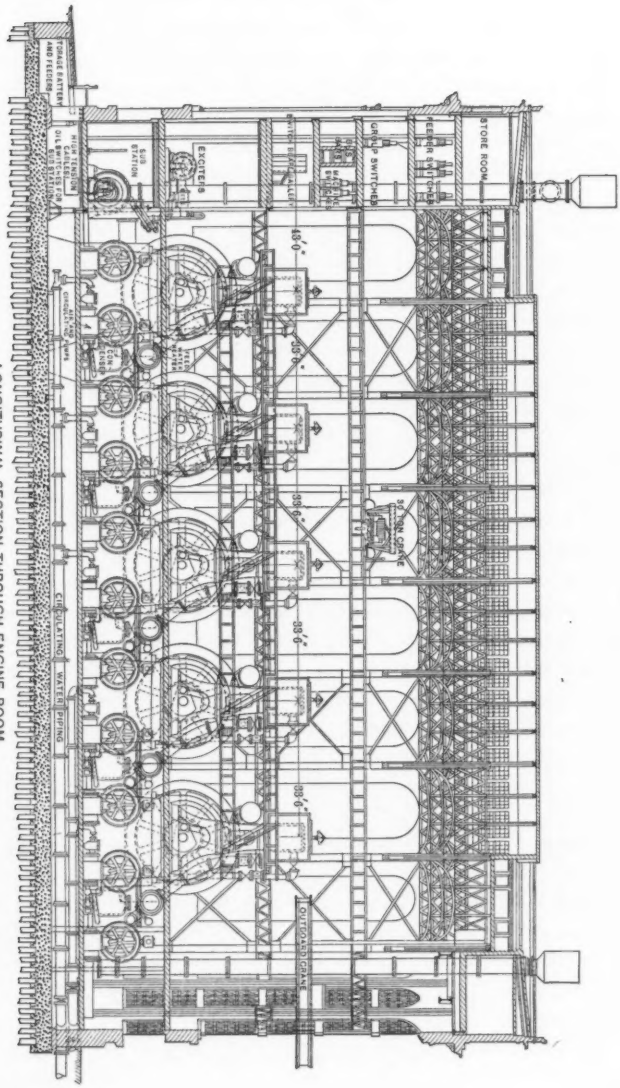
The Engine House.—The engine house has a sub-floor at Elevation + 10, the engine floor being at Elevation + 29. At the west end there is a series of floors at Elevations + 54, + 77 and + 91. These are 22 ft. wide, and are to be used as switch-board galleries. At the top there is a pent house running around on the four sides of the engine house at Elevation + 102.

The engine house has large headroom, and is trussed across by heavy steel trusses 22 ft. 8 ins. apart. These carry a lantern in the center and the pent house on either side.

At the switch-board end, at one corner, there is an elevator and stairway for visitors. At the other corner of the switch-board galleries a spiral stairway is provided especially for the use of the employees. At the other end of the engine house, and in one corner, there is an elevator and stairway in a brick enclosure running up to the pent house and storeroom, with doors to the engine-house floor and each successive floor of the boiler house.

Chimney.—The internal diameter of the chimney is 22 ft., and its height is 353 ft. It is higher than any chimney in this country, and of larger diameter than any in the world. It was built the summer before the building, except the foundation walls. In order to keep at work as many bricklayers as possible, it was built from both inside and outside scaffolds, up to a height of 125 ft., and two material elevators were used. From that elevation to the top a scaffold and elevator was carried on the inside only.

It is built mostly of common brick, and contains a lining of fire-brick extending about 50 ft. above the highest flue opening. It has two shells. The inner is just thick enough to support its own weight, including the fire-brick lining; the outer carries its own weight and the horizontal wind load, taken at 50 lbs. per foot. To resist this overturning moment, and to stiffen the outer shell, counterforts or



LONGITUDINAL SECTION THROUGH ENGINE ROOM.

LOOKING NORTH

FIG. 3.

ribs were built into it, as shown in Fig. 5. These reach within about 2 ins. of the inner shell and form a guide for its movement by expansion or contraction. The capacity of the chimney was figured by Rankine's formulas. Brick was used instead of steel because masonry is the more durable material. The chimney was carried high in order to avoid the use of exhaust fans or blowers, and because it was thought better to let the foul gases escape at as high a level as possible. It contains about 3 400 000 brick, and rests on a block of concrete 20 ft. thick and 88 ft. square.

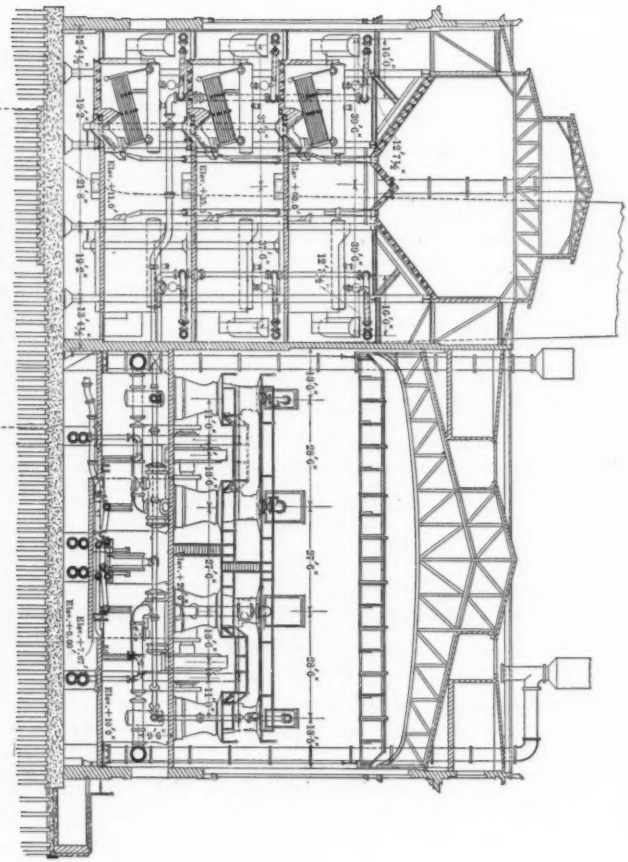
The flues enter from opposite sides on each of the three floors, and a baffle wall in the center, reaching just above the highest flue opening, directs the gases upward and prevents the discharge from one side tending to choke up the opposite flue.

The chimney is surmounted by an iron cap, cast in sections and bolted together (Fig. 6). The whole is topped by a series of lightning rods, which are grounded by copper ribbons on opposite sides.

Fig. 1, Plate X, shows the excavation for the chimney, partly filled with concrete, and also shows some of the concrete for the surrounding foundations. Fig. 1, Plate XI, is a view of the chimney showing the height to which the outer scaffolding was carried.

The Building.—The building is of brick. The outside is faced with iron-speckled brown brick and is trimmed with granite and with brown fire-flashed terra cotta. The window frames are of iron, and the cornice and monitor trimmings are of copper. Fig. 2, Plate XI, is a view of the completed building, from the river end. The inside walls of the engine room are of common brick, but there is a wainscoting of enameled brick up to about 9 ft. above the floor. The walls are for the most part self-supporting. The floors, floor loads, roof, roof loads, boilers, coal pocket and contents are carried by the columns. There is a heavy cornice of terra cotta blocks near the top of the building and this is partially supported and anchored by iron frames, but these are so constructed as to allow a slip down of 1 in. if the wall below should shrink or settle away that much from the iron frame of the building. Other mouldings, cornices, etc., are built into and supported entirely by the walls. Fig. 2, Plate X, shows the ironwork of the building during erection.

The floor loads allowed are as follows: Engine-room floor, 400 lbs. per square foot on the part between the engines, and 600 lbs. in front,



CROSS-SECTION OF POWER STATION LOOKING WEST.

FIG. 4.

which amply allows for the concentrated loads of the exciter engines and exciter switch-board; sub-engine room floor, 225 lbs. between the engines, with special provision for condensers, heaters and pumps; and 600 lbs. in front where are supported the transformers and rotary converters for a sub-station for the power-house locality; 225 lbs. per square foot on each switch-board floor; 175 lbs. on the pent-house floor; 100 lbs. for the roof; 425 lbs. on the boiler-house floors for the part in front of the boilers, and 225 lbs. for the space between and back of the boilers. These figures include the allowance for the floor itself and for the superficial loads.

No provision was made for longitudinal expansion, as it was considered that it would act each way, from the big brick chimney as a fixed point, and take care of itself. The boiler-house joints are mostly bolted at the bottom, so as to absorb some of the expansion, and are solidly riveted at the top. For lateral expansion the engine-house roof trusses are hung on end pins to allow for any slight movement north from the boiler house, which is rigidly held. The engine-house columns are very long, and those on the north side are wide enough and strong enough to resist the vertical load as well as the horizontal outside wind load.

The wind load was taken at 30 lbs. per square foot at the top, and was decreased somewhat toward the bottom. The columns were made strong enough to resist this wind pressure on a span extending from the end truss pin to the ground, as it was anticipated that the engine floor and sub-floor would not be put in until some time after the building was erected. On the south side of the engine room, the columns are of the same outline, but of considerably lighter metal, as they will have no wind load to resist. The engine-room trusses are pin-connected along the bottom chord and riveted at the top. They carry not only the roof and its load, but also the pent house and its load.

The wind pressure from the east or west is resisted in the engine room by a lateral system in every other bay. This starts in the roof and is carried down to the column bases by diagonal rods and lateral braces. The traveling crane girder, engine-room floor girder, etc., are incorporated with this system.

In the boiler house the columns carry not only the floors and the boilers, but also the coal pockets and, in addition, the roof and its load.

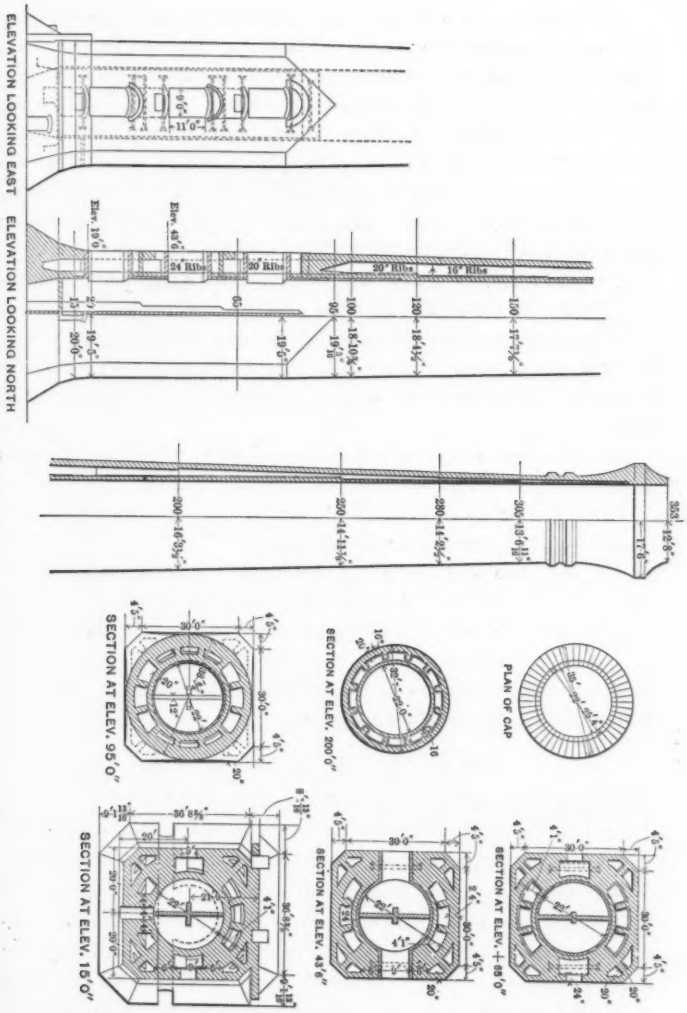

ELEVATION LOOKING EAST
ELEVATION LOOKING NORTH
Elev. 19'0"
Elev. 43'6"
24 Ribs
20 Ribs
20" Ribs
16" Ribs
SECTION AT ELEV. 95'0"
SECTION AT ELEV. 200'0"
PLAN OF CAP
SECTION AT ELEV. +65'0"
SECTION AT ELEV. 43'6"
SECTION AT ELEV. 15'0"

Fig. 5.

Each pair of columns in the center of a battery is braced diagonally from floor to floor from the coal pocket down.

The large coal pockets presented quite a problem. The tendency to burst or spread out is resisted entirely from the outside, there being no exposed iron whatever in them. The pockets are lined with I-beams spaced 2 ft. or more apart and varying in depth from 10 to 15 ins. These are filled in with concrete which is carried to about 3 ins. over their tops and then covered with a waterproofing material. The concrete surface was left fairly rough in order to prevent the waterproofing from sliding, or peeling off. The section of the pockets is shown on the cross-section of the building, Fig. 4, and the ends are vertical.

The pressures, of course, are calculated for a maximum load, the conditions for which are that the pockets shall hold as much as they can be made to by trimming, that is, that the coal should slope up from the tops of the vertical sides, at the angle of repose, to the summit. The pockets can be filled by the conveyors almost to this limiting line.

The pressures on the vertical surfaces were calculated by Rankine's formula for a retaining wall with superimposed loads:

$$p = wx \cos \phi;$$

in which p = pressure on a unit of surface,

w = the weight of a unit of volume of the material,

x = the depth below the top of this unit of surface,

ϕ = the angle of repose of the material, or the angle of the top slope.

The pressure is parallel to the surface of the material. Then the total pressure on a vertical surface is

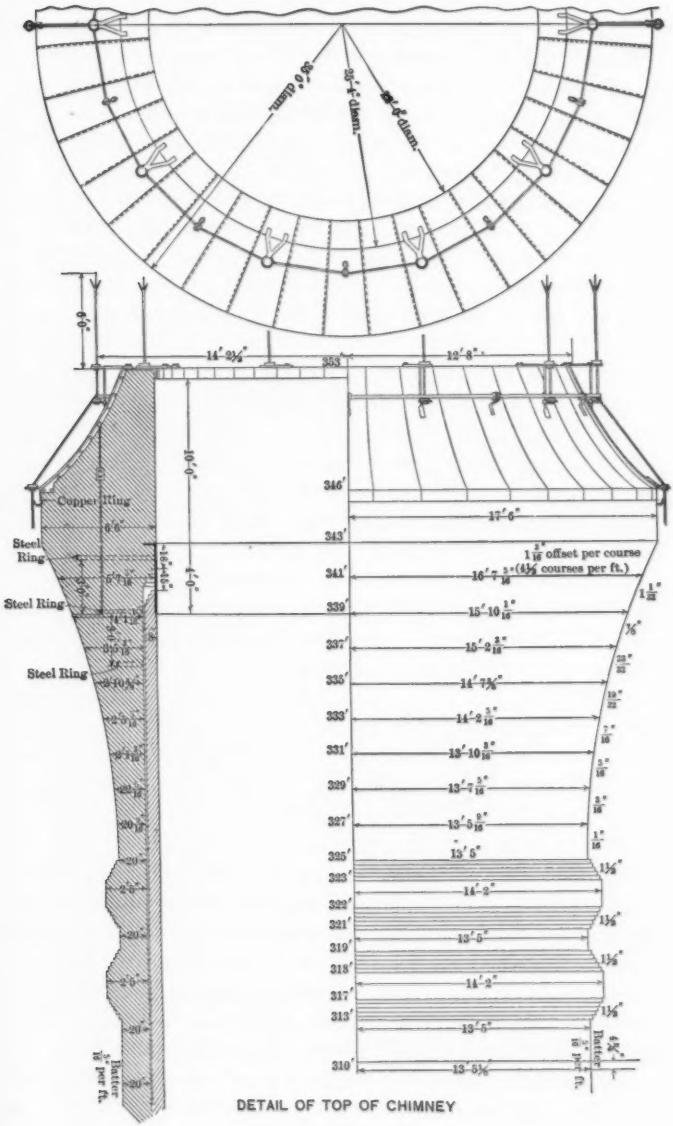
$$P = \left(\frac{d_1^2 - d_2^2}{2}\right) w \cos \phi$$

where d_2 = the depth of the top of the surface, and

d_1 = the depth of the bottom of the surface below that point in the top surface of the material directly over the surface.

The weight of a cubic foot of coal was assumed at 56 lbs.

The pressures on the inclined side portions were obtained by considering each surface as composed of a series of steps, and assuming the pressure on the slope to be the resultant of the vertical dead load multiplied by cos ϕ on the horizontal part of each step, and the thrust on the vertical part as calculated by Rankine's formula.



DETAIL OF TOP OF CHIMNEY

FIG. 6.

The calculated pressures on the vertical faces of these steps were reduced when the so-called line of maximum pressure—that is, the line bisecting the angle between the vertical and the slope of repose—cuts beyond the crest of the coal slopes; that is, intersects the opposite receding slope, or that slope produced, first instead of the rising slope, and by the amount that the part *B C* (Fig. 7) of the line between the opposite receding slope at *B* and the ascending slope at *C* produced, bears to the whole line, up to the ascending slope line produced, or *A C*.

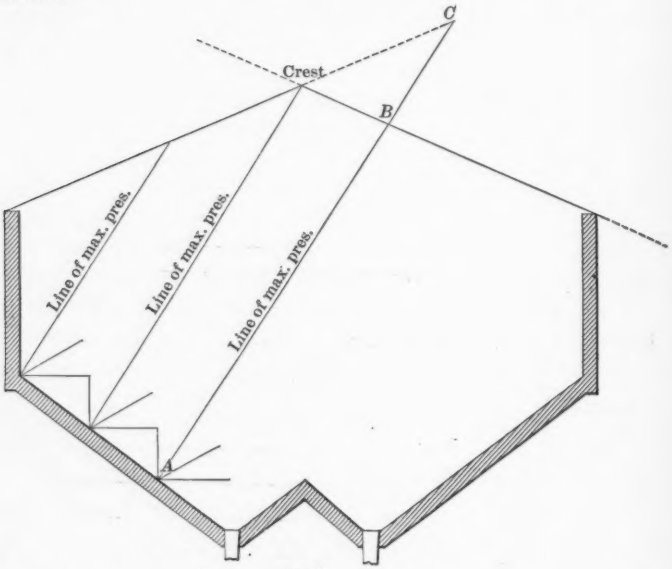


FIG. 7.

In the bottom of the pocket, the two slopes of the crown piece counteracted each other, and therefore it was only necessary to make the V-pieces strong enough to resist this pressure, and the main cross girder only strong enough to bear the vertical load and the tension induced by the side pressures. At the height where the bottom of the vertical portion meets the top of the inclined part there is a horizontal trussing, made strong enough to carry a large portion of the lateral thrust to the corners, and the corners are made strong enough to resist a powerful distorting force.

Across the end of this level there are horizontal trusses strong enough to take the entire end thrust to the corners and thence down the sides where it will be taken up by the frictional resistance of the coal, or, if the pocket is full, it will be partially resisted by the opposite end pressure transmitted along the side pieces.

This was done to provide against any possible bursting tendency of a sudden settlement, one-sided load, or other cause; even for the remote possibility of a slight earthquake.

The strains on the steel, and the loads on the columns and brick work were made to agree with those allowed by the Building Department of New York City by the law used in 1898, before the present law went into effect.

Erection and Cost.—The building excavation was sheet-piled all around because the surrounding material was too soft to take any reasonable slope naturally. The ground-water was easily kept down with one 3-in. and one 6-in. pulsometer, although to do this it was necessary to drive two rows of sheet piling and puddle between them where the cribs running east and west passed out from under the building to the bulkhead. The sheet piling was 3 x 12 ins.

For the chimney foundation a row of 10 x 12-in. tongued and grooved sticks was driven around it in the form of a square. The enclosed space was then excavated to the required depth. The corners were well braced and the piles were driven from the surrounding cellar bottom by attaching to the regular pile drivers sticks corresponding to ordinary derrick booms, and hanging to their ends pairs of ways reaching to the bottom of the chimney excavation. In these ways the hammers were moved and the piles were driven. By this method it was possible to keep several machines at work on the somewhat limited area, and the bother and expense of lowering a machine into the hole and lifting it out again was avoided. The sidewalk vault was excavated and built after the building was nearly finished. The shoring for the earth outside was braced against the building.

Much of the iron-work was erected with house derricks and those of the ordinary form, but the engine-house roof required quite an extensive traveler. At one side it was supported on the tops of the engine foundations and at the other it was at first built on high blocking, and, after two spans (or one bay) of the engine room were up, it

was allowed to run on that side on the main-crane girder, on account of the temporary engine house being in the way.

So that the erection of the engines might proceed before the engine-room roof proper was put on, a temporary roof was suspended from the trusses in the two bays of the engine room over engines Nos. 1 and 2.

The intake pit for the circulating water was made by driving 10 x 12-in. tongued and grooved sticks around on its four sides and using these for its walls, both supporting and retaining.

The roof load is distributed on these sheet piles by framing the roof beams into a heavy beam running continuously along the wall. The sheet piles are cut off so low that, while they are not below tide-water, capillarity will keep them wet and reduce decay to a minimum.

To receive the large engines and generators a runway was built on a level with the engine-room floor from the bulkhead to an opening left in the wall; so that, after a single movement from the lighter to the runway, by means of a floating derrick, the parts could be rolled within reach of the large traveling crane.

Cracks in masonry seem to be unavoidable, and two small ones, running from the flue opening upward for a short distance, developed in the chimney, immediately after it was put in use. These have not increased in size, and there have been no settlement cracks in the building, chimney, or machinery foundations.

The excavation, of which there were about 25 000 cu. yds., cost about $1.20 per yard. About 8 000 piles were used. The 35-ft. piles cost $5.50 apiece, and the 45-ft. piles under the chimney cost $7.50 apiece, driven. The concrete used was a mixture of one part cement, two parts sand and four parts broken stone, and cost $5.00 or $4.50 per cubic yard, according to whether American Portland or Rosendale cement was used. The former was used in the foundation concrete and the latter above Elevation + 0. The chimney, above the elevation where the brickwork commences, cost $20.50 per thousand for everything, including damper ironwork, cap, lightning rods, etc.

About 4 000 tons of iron were used for the building, including architectural cast-iron as well as structural work. The total cost of the station, including machinery, will not be far from $3 000 000.

The foundations were put in during the summer and fall of 1897. In 1898 a temporary engine house, shown in Fig. 2, Plate X, was

FIG. 1.—CHIMNEY EXCAVATION AND CONCRETE FOUNDATIONS.

FIG. 2.—FOUNDATIONS OF ENGINES, AND FRAMEWORK OF BUILDING.

built inside the proposed permanent one, and several boilers were erected on the first floor of the boiler house and temporarily closed in. See Fig. 1, Plate XI. These gave an electric power of 1 700 K.-W. for about a year before the permanent plant was put in operation.

The chimney and engine foundations were also put in during 1898. In 1899 the building was erected, and during that year the plant was pretty completely equipped.

Engines, Generators, Etc.—In the engine room there are eleven large vertical cross-compound engines, each directly connected to a three-phase alternating current generator in the center between the cylinders. The engines are piped so that either cylinder may be operated alone, and in that case each is capable of generating 4 500 H.-P., maximum. The engines are each of 4 200 H.-P. normal, and of 6 600 H.-P. maximum, capacity. Each generator has a capacity of 3 500 K.-W., and is capable of carrying a 50% overload for a short time.

For a medium-sized cross-compound engine it is quite customary to ship the shaft, cranks, fly-wheel hub and generator hub in one assembled piece. This was deemed inadvisable in this case, on account of the great size and weight of the pieces and the difficulty of moving them. The pieces were, accordingly, shipped separately, the largest pieces being the shafts, which weighed about 35 tons. Each shaft and the pieces pertaining to it were assembled near their foundation, the different parts being forced on the shaft by means of a hydraulic pressure of over 300 tons.*

The shaft is a large hollow forging of 37 ins. maximum diameter, the hole being 16 ins. in diameter. The cranks are of the style known as fan-tail, in distinction from disc cranks or the ordinary unbalanced cranks.

The cylinders are 46 and 86 ins. in diameter, the stroke is 60 ins. and the number of revolutions is 75 per minute. The fly wheels have a rim speed of 6 600 ft. per minute. They are built up; the hub, arms and central third of the rim are of cast steel, and the outer thirds of steel plates. The plates are in thicknesses of 1 in., no two joints come opposite, and they are fastened to the central part and to each other by long 2-in. steel rivets, which were driven cold by hydraulic pressure.* The fly wheels are very heavy in order to absorb quickly the

* A description of this work can be found in *Power* for August, 1899.

speed variations, for which displacement curves were very carefully calculated.

The valves are of the Reynolds-Corliss type. The valve chambers are cast in the removable heads of each cylinder, and are at the center, a new scheme by Mr. Reynolds, of the Allis Company, by which clearances in the cylinders are reduced.

The connecting rods are of the locomotive pattern, that is, I-shaped instead of round, and the bearings are water-jacketed, as well as piped for the oil supply.

The generators are of the revolving-field type, with fixed outside armatures. The revolving field has 40 poles, and an alternating current of 6 600 volts is generated. The armature was shipped in two pieces and the field in several pieces, as follows: The hub or spider, the rim in four parts, and each pole piece by itself. The armature is of the side-moving type, as made by the General Electric Co., and the pole pieces may be exposed to view without removing the top half of the armature.

The engines stand on the floor at Elevation + 29, and reach about 36 ft. above the floor. Fig. 1, Plate XII, is a view of Engine No. 1, during erection. Fig. 2, Plate XII, shows the interior of the engine room, with eight engines nearly completed.

A separate feed-water heater and condenser is provided for each engine, and is placed in the space under the floor and between the engine foundations. Each condenser has a steam engine driving a single-cylinder circulating water pump and a two-cylinder air pump, the cylinders of which are on either side of and are part of the same frame as the circulating water cylinder. The single steam cylinder is directly over the circulating water cylinder in the center. The exhaust steam from the pumps is so connected that it may be turned into its condenser, into the low-pressure cylinder of its large engine (and thus used expansively), or conducted back into the boiler house to the secondary feed-water heaters.

The exciters are placed at the west end, under the switch-board galleries. Provision has been made here for steam-driven exciters of 60, 30 and 60 H.-P., respectively. The drivers are tandem-compound high-speed steam engines of the "Ideal" make, and are directly connected to small direct-current generators. There is also space for an exciter switch-board and a battery of three electrically-driven exciters, each consisting of a generator coupled to a motor.

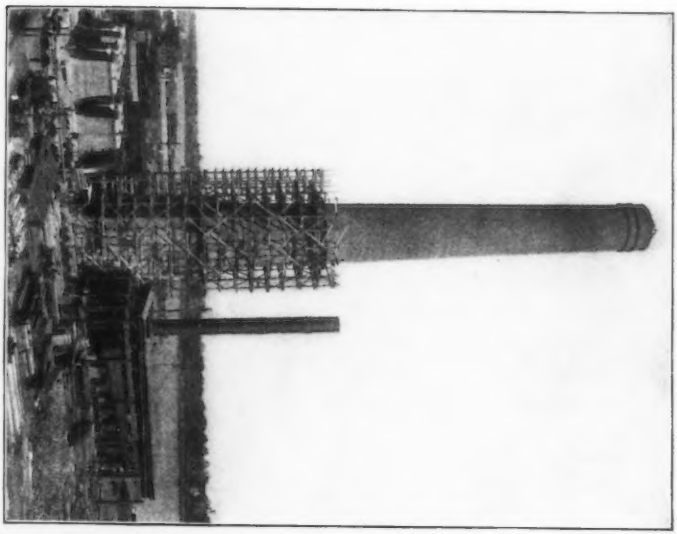


FIG. 1.—CHIMNEY NEARLY COMPLETED, AND TEMPORARY BOILER-HOUSE.

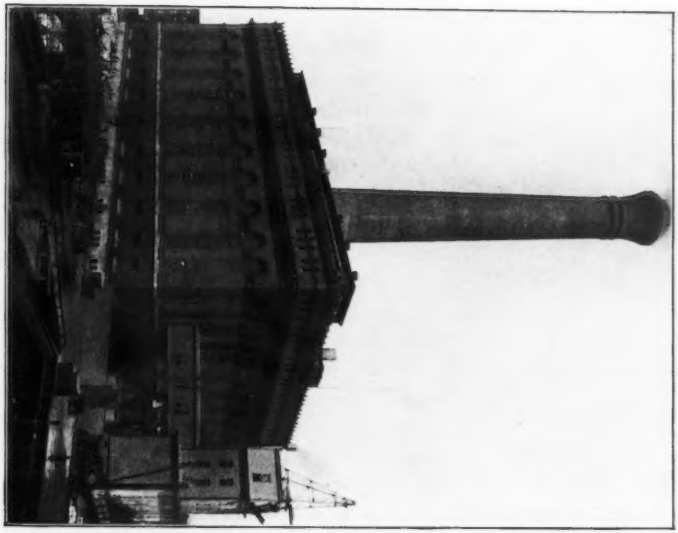


FIG. 2.—VIEW OF THE STATION FROM THE RIVER.

The entire complement of engines has not yet been installed, nor has the third floor of the boiler house been filled. The other engines will be needed if the load of the Third Avenue Railroad is thrown on this station, and the remainder of the third tier of boilers will be filled out with the boilers from the various small electric and cable-driving stations about town, as these stations are discontinued.

The Boilers.—There are 87 boilers, set in three tiers of 29 each. Each boiler is of about 500 H.-P., ordinarily, or 800 H.-P., maximum. These are known as 250 H.-P., ordinarily, when rated by the Philadelphia Centennial Standard, or an evaporation of 30 lbs. of water for 1 H.-P. They are equipped with mechanical stokers, coal chutes to feed them with coal, and ash chutes to convey the ashes to the basement. The stokers are driven through jack-shafts near the tops of the boilers, and the bearings are bracketed out from the columns.

Each line of from 6 to 8 boilers has two small Westinghouse steam engine drivers on platforms between the batteries, the other spaces being planned to be occupied by electric motors. The shafts are propelled by means of link belts. Above the boilers is the coal pocket, divided in half by the chimney, and fed by two link-connected overlapping bucket conveyors, Fig. 8. The total capacity of the double coal pocket is 10 000 tons.

Cranes.—The engine room is provided with several cranes. There is a large three-motor electric crane of 110-ft. span, built by Wm. Sellers & Co., and capable of lifting and carrying 30 tons. An outboard crane feeds the traveler from Exterior Street, and has a hand trolley of 30 tons capacity. A small hand-power crane of 15 tons capacity runs under the first switch-board gallery cross-wise of the building. Another similar one is located directly below it for the sub-station. Provision is also made for a trolley over engine No. 11, and feeding from that to the outboard crane.

Coal and Ash Conveyors.—Coal is unloaded at the wharf by a tower with a fixed horizontal boom, and is transmitted into the pockets by two bucket conveyors. The buckets are 24 x 28 ins., and overlap so as to be continuous-loading without the use of a filler. Sufficient vertical space is provided in the tower for a crusher, if the coal is lumpy, and for two weighing hoppers to be used before the coal is emptied into the conveyors. Each conveyor makes two vertical turns

of 90° and a horizontal twist of about 30 degrees. The length of each conveyor is about 800 ft.

The ashes are picked up from the chutes in the basement and transferred by small trucks on parallel tracks, or by two conveyors, to the river end of the building. Here they are dumped into a vertical bucket conveyor and carried up to the second story where they are again dumped and carried to the ash pocket by the returning coal conveyor. The ash pocket is under the coaling tower, and is about 25 ft. wide and 60 ft. long. It is high enough and of sufficient V-shape to discharge its contents by four chutes into scows at the dock.

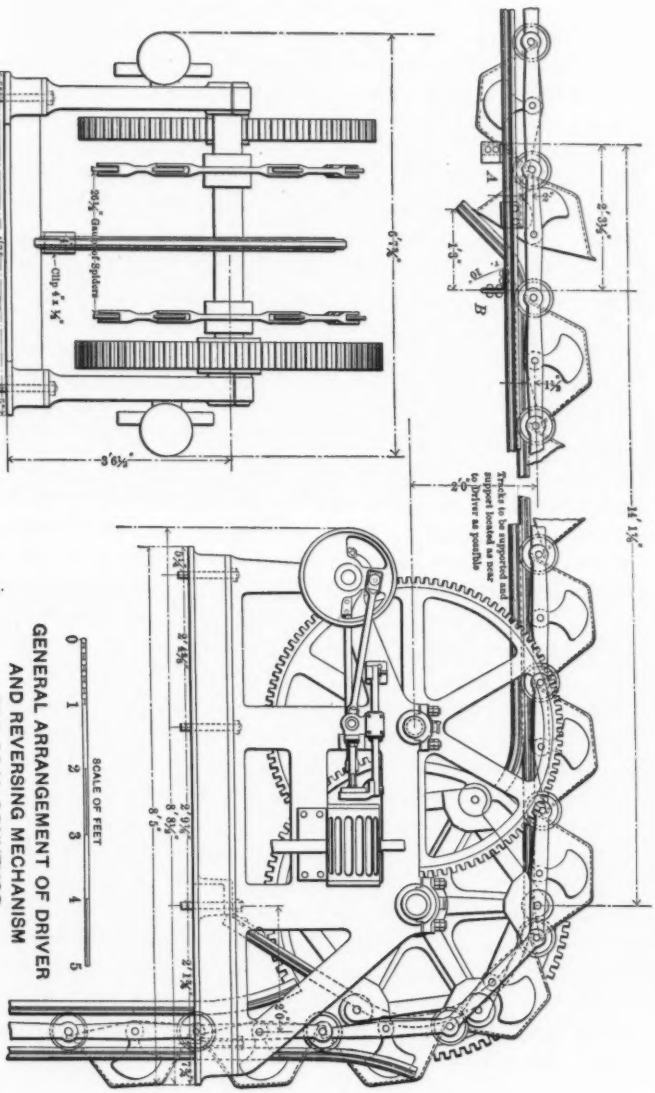
Each conveyor is driven by a separate steam hoisting engine. The conveyors are supported from the coaling tower to the building by a steel bridge having a passageway between and on either side of the conveyors. The vertical portions are encased in steel frames, and here the twists are made. The top horizontal parts are supported on the boiler house trusses.

Steam Piping.—The maximum diameter for the mains of the steam pipe system was fixed at 16 ins. on account of the difficulty of placing in position curved lengths of larger size. It is also more difficult to provide expansion for larger sizes and to keep them tight.

At each end of each floor in the boiler house there is a 16-in. loop, and the loops at each end are connected to each other. Each boiler is connected to the line of pipe back of it. Each floor has a connection to each stand-pipe, of which there are as many as there are large engines, 11 in all. These are situated near the loops, in the spaces between the batteries of boilers. From the bottom, and below the level of the engine-room floor, a connection runs across to each engine. Before the steam enters the high-pressure cylinder, it goes through a separator. If necessary, steam can be supplied to any engine from any floor of boilers at either end, although, of course, under normal conditions, steam will be taken from the adjacent part of one of the loops.

Any damaged portion of a steam pipe may be cut out by means of valves in the boiler house without cutting out more than one battery of boilers. A leak or break in the engine room would of necessity cut out one engine. There are various small steam pipes for the smaller engines.

The pipe is all of rolled steel with cast-steel fittings. The flanges made of the latter are in part riveted to the pipe and in part connected by the Van Stone patent.


A
B
Clip 6 x ¾"
Pedestal to be supported and bolted as near Bracket located as near to Driver as possible
SCALE OF FEET
0 1 2 3 4 5

GENERAL ARRANGEMENT OF DRIVER AND REVERSING MECHANISM FOR COAL CONVEYOR.

FIG. 8.

Exhaust Mains.—Four 42-in. risers are provided for free exhaust, or one for each three engines; and each engine exhaust is provided with a back-pressure valve. In the boiler house there are also smaller exhaust risers as outlets if the exhaust for the feed pumps and auxiliaries is passed through the secondary heaters. The water condensed from each large engine is passed through into its separate hot well where it can settle, become cool and have most of its oily matter removed by a filter at one end. The hot wells are large enough to hold the water for about half a day, if none is passed away and wasted.

Water and Gas Supply.—The water supply is obtained from two separate systems: A main on Second Avenue supplying a section of the city further down town, and a small main supplying the immediate locality. The former connection is on Ninety-fifth Street, is 12 ins. diameter, and is piped to four 6-in. meters. The latter connection is on Ninety-sixth Street, is 6 ins. diameter, and is piped to two 6-in. meters. From the meters the water can go either direct to the feed pumps or to two tanks which may be called equalizing tanks, and in which the water is received from the various sources and mixed or equalized. There is also a 12-in. connection for salt water, which may be used in the feed system if other sources fail, or it may be used for flushing out the basement.

An emergency gas connection will probably be made, so that, if the electric power is absolutely suspended for any reason, the building will not be without light.

Feed-Water.—The feed-water system is provided with three duplex steam-driven plunger-packed compound pumps, of horizontal pattern, and an alternative system consisting of a gang of inspirators capable of elevating a portion of the supply required. The pumps have to work against a pressure of from 160 to 180 lbs.

The feed-water is pumped from the equalizing tanks, or the mains direct, into long mains under the first floor. From these it passes into one or all of the primary heaters in the engine room, or directly into risers which feed through loops into the boilers on the various tiers. From the primary heaters it returns either to the secondary heaters or to the boilers directly. If taken through the secondary heaters it then passes to the boilers. Thus it may take one of the following three courses: To the boilers direct, either at the street temperature, or with that temperature modified by the hot wells; to the

FIG. 1.—ENGINE NO. 1, DURING ERECTION.

FIG. 2.—THE ENGINE ROOM.

primary heaters and then to the boilers at a temperature of about 125°; or, through both the primary and secondary heaters and then to the boilers at a temperature dependent on the number of secondary heaters installed and the amount of exhaust steam turned into them. If a maximum of four were put in, the temperature would be as high as 200°, or not much below the boiling point.

Circulating Water Piping.—The circulating water system consists of four 30-in. suction mains and four 30-in. discharge mains. Each main supplies three large engines. The circulating water is drawn from a basin or well in the vacant space just inside the bulkhead. It is connected with the river by two 42-in. pipes laid through the bulkhead. The discharge mains go out through the bulkhead and discharge into the river. The water drawn in is taken at a much lower level than that at which the discharge is made. The two masses of water at the widely different temperatures are expected to be kept apart sufficiently by this difference in level.

Oil System.—New oil and old oil from the mains is received at the Exterior Street end of the building, near the entrance and in the basement of the engine room. Three duplex pumps are provided to lift the oil up into the oil room. There it can be passed through one or two filters, or taken directly into one of the receiving tanks in that room. From the oil room, at Elevation + 84, the oil is piped to all parts of the large engines, and also to most of the small engines with sufficient head.

Sub-Stations.—Electric sub-stations have been laid out and several have been installed. As soon as these are finished and the cables are removed, the various cable and direct-current electric stations in the city will be gradually abandoned.

The outfit for the sub-stations consists of several rotary converters, their transformers and a couple of blowers to keep the latter cool.

Contractors.—The main features of the engineering work were by the following firms: Most of the structural work was done by the New Jersey Steel and Iron Co., the masonry by M. Reid & Co., the large engines by the E. P. Allis Co., the generators by the General Electric Co., and the boilers by the Babcock & Wilcox Co.

Staff.—Much of the small piping was done by day's work under the direction of the company's engineers, and many small bits of ironwork were let to various firms in the city. The writer had general

charge of the plans in the office, and made many of the calculations under the supervision of the Chief Draughtsman, C. E. Corby, Assoc. M. Am. Soc. C. E., and the Chief Engineer, M. G. Starrett, M. Am. Soc. C. E. F. S. Pearson, M. Am. Soc. C. E., was Chief Engineer when the building was commenced; and afterward and up to the present time, Consulting Engineer.

Mr. W. A. Low was the Civil Engineer, and Mr. A. S. Mann the Mechanical Engineer, at the building site, in charge of the work.

Mr. A. V. Porter was the Architect of the building, and Albert Carr, Assoc. M. Am. Soc. C. E., at that time the company's Principal Assistant Engineer, looked after the foundation work for the new building. Mr. W. A. Pearson, Chief Electrician for the company, superintended the wiring and switch-boards, and Mr. R. C. Brown was assistant to Mr. Starrett during the construction of part of the work. All the work was done at the office of the company, except the designing of the engines, generators and other machines. General and special features of these were specified. A large portion of the structural iron-work was designed under the supervision of, and checked by, J. T. N. Hoyt, Assoc. M. Am. Soc. C. E., and the remainder, including the coal pocket, by the writer.

Summary.—The station is unique in the following respects, at least: It is the largest steam-power plant in the world, and generates more power per square foot of ground surface than any other. The power generated is 0.94 H.-P. per square foot as an average, or 1.47 H.-P. as a maximum, for the building only; or 0.70 H.-P. per square foot as an average, or 1.10 H.-P. as a maximum, for the whole property, down to the river.

Everything proceeded smoothly, although somewhat slowly, as is frequently the case with such a large piece of work. Many of the schemes adopted may be criticised, but they were selected after a careful consideration of all available methods. Expense has not been spared. It was the rule to obtain the best, but as cheaply as possible. Considerable attention has been paid to the interior and exterior appearance.

The writer is much indebted to the company for the use of the photographs accompanying this paper, and to Mr. Corby for reviewing the same and advising him of the progress of the work.

DISCUSSION.

F. L. AVERILL, Assoc. M. Am. Soc. C. E. (by letter).—The design of coal pockets for steam plants has, within a few years, received considerable attention, both as to the stresses induced in the framing and in the details of construction. It is to be hoped that the author will incorporate further details of this notable pocket in the final publication. Mr. Averill.

With the present knowledge of the subject, it is surprising to note how recently large steel pockets have been erected without precautions being taken to avoid the certain corrosion. There have even been cases where some of the principal members of the framing have been exposed to contact with the coal.

The disastrous failure of a large pocket in Paterson, N. J., in 1897, created a discussion, among engineers and in the technical papers, of much practical value, which has borne fruit in the more recently designed pockets.

The maximum loading and the prevention of corrosion are now well defined in good practice. There is another point sometimes lost sight of in the design of such pockets: namely, avoiding "dead spaces" between the chutes, where coal can remain lodged. It is asserted by men of experience that any mass of bituminous coal left stationary is certain, sooner or later, to ignite by spontaneous combustion. The writer knows of one large storage pocket where men are sometimes put in to move coal by hand to guard against danger from fire.

The writer recently had to design a coal pocket for the United States Bureau of Engraving and Printing, at Washington, D. C., incident to extension and improvements in the steam plant. There were limiting conditions, partly architectural, so that an ideal arrangement of coal-handling apparatus was impossible. The scheme of framing and the details of construction, however, may be of interest.

The bottom part of the pocket was made in the shape of several inverted pyramids, thus avoiding any spaces for the lodgment of coal, and at the same time permitting the use of deep lattice girders between the several pyramids. These girders give stiff bracing, and support a large proportion of the load.

Expanded metal, wired to angles, was used to prevent the cracking of the concrete.

For the vertical sides of the pocket, brick filling was used between the beams, as one side of the pocket formed the outside wall of the building.

Since reading Mr. Montony's paper the writer has determined to recommend waterproofing in addition to the cement and concrete protection for the pocket at the Bureau of Engraving and Printing.

Mr. Averill. The writer was ably assisted in the foregoing work by Kort Berle, Assoc. M. Am. Soc. C. E., who made most of the calculations and worked out the details.

Mr. Carr. ALBERT CARR, Assoc. M. Am. Soc. C. E.—In regard to the construction of the foundation work there are some minor points which the author might have put a little differently if he had consulted with some one having to do with the execution of the work.

The only point of real importance, perhaps, is the statement in regard to cement and concrete. The author states that "the concrete used was a mixture of one part cement, two parts sand and four parts broken stone, and cost $5 or $4.50 per cubic yard, according to whether American Portland or Rosendale cement was used." So far as the speaker is aware or has any record, not a barrel of Rosendale cement was used in this work, and no concrete was mixed in the proportions quoted.

The concrete under the chimney was nearly all mixed in the proportions, 1 part cement, 3 parts sand and 5 parts broken stone. The concrete outside the chimney was nearly all mixed in the proportion of 1 part cement, 4 parts sand, 4 parts ¾-in. broken stone and 4 parts 1½-in. stone.

The cost quoted is substantially correct, but the difference in cost is due to the difference in the proportions of material used, and not to difference in cement, as stated. Also, a small part of the difference in cost is due to the fact that part of the concrete was machine mixed and part hand mixed.

The author states that the excavation for the building was sheet-piled all around. The excavation was sheeted on three sides complete, and on the fourth side only far enough to cross the cribs which are mentioned. It is an interesting feature of the sheet-piling that the side of the excavation left unsheeted was toward the East River, which was about 60 ft. distant.

The sheet-piling crossing the cribs mentioned consisted only of a single line of 10 x 12-in. tongued-and-grooved timber, and was not puddled. Two lines of sheet-piling were driven across the crib at the north side of the excavation, but the driving of the second line was due to a change in location of the east wall of the building, and not because a single dam was not entirely successful in holding back the water.

Mr. Low has amplified Mr. Montony's description of the sheet-piling around the chimney foundation. The speaker is responsible for the plan of holding back the sheet-piling by tie rods instead of using the ordinary method of bracing inside the foundation, and he was much gratified at its success. Three sides of the excavation were kept practically in straight lines, and the fourth side bulged into the excavation only 6 ins., so that there was no serious movement in the

material back of the sheet-piling. By this method the expensive and troublesome bracing inside the chimney was done away with, and the entire space inside of the excavation was available for the use of pile drivers. All piles were driven without moving the timbers, as would have been necessary with the ordinary method of bracing. Mr. Carr.

The author seems to imply that the plan of using piles under the foundation was adopted because the character of the soil was not known with sufficient definiteness.

Test borings were made, as stated, over the plot to a depth of — 75 ft., but one preliminary boring was carried to rock, which was found at — 123 ft. The original intention was to found the chimney upon rock, and if the depth had not been more than 75 ft. this plan would have been carried out, but it was not deemed feasible to carry the foundation down to — 123.

The borings showed, as stated, filled-in material to the depth of about 15 ft. Below this was a stratum of packed river mud or clay, about 10 ft. thick, and below this were strata of sand beginning with coarse sand on top, and gradually increasing in fineness until about the level of — 30, where fine beach sand was encountered. This stratum of fine sand determined the length of the piles.

Many test piles were driven to refusal, and these indicated that sticks about 45 ft. long could be used. Very few piles, however, over 40 ft. long were driven. The piles were driven to a 1-in. penetration with a 2 500-lb. hammer dropping 20 ft.

In other respects, so far as the speaker is aware, the statements made by the author are correct, and the discrepancies noted are probably due to the fact that plans were sometimes changed in the field after the design had left the Chief Engineer's office.

W. A. Low, Esq.—There was a little settlement of the chimney, but that was anticipated. Careful records were kept from week to week. The speaker took the levels once a week, and found that, as the chimney went up, it gradually settled a little, and to-day the total settlement is under 3 ins., most of that taking place before the chimney was completed. Since the chimney has been completed there has been added the weight of part of the three boiler-room floors and the coal pockets, where the coal is stored. In the settlement, taken on all four corners at the base, a variation of not more than $\frac{1}{8}$ in. is found in any of the four corners compared with any of the others. Mr. Low.

The speaker does not know how much of that settlement was due to shrinkage in the concrete.

The load on each pile under the chimney foundation was between 15 and 16 tons. The speaker does not know the load on the piles under the other part of the building.

Two rows of guide piles were driven down and two 12 x 12-in. guide stringers, 10 ins. apart, were bolted to them to accommodate the 10 x 12-in. sheet piles.

Mr. Low. Along the south side of this dam this method had to be changed, as it was found that one line of guide piles struck the timbers of one of the old cribs, causing them to glance inward. Consequently, a single row was driven and the guide stringers were bolted on either side; then, as the sheet piling progressed, the guide pile immediately in front of it was drawn by means of a lever, and so on until completed.

Owing to the fact that this dam—the inside dimensions of which were 88 ft. by 85 ft. 4 ins.—had to be excavated to — 20 ft., and as the piling had to be carried on along the outside of it, it became necessary to take the utmost precautions to prevent the sides from giving way.

Consequently, anchor rods, 1½ ins. in diameter and 30 ft. long, were secured through the guide stringers at intervals of about 5 ft. by means of washers 8 ins. square and nuts and anchored to 12 x 12-in. timbers laid behind the rows of foundation piles already driven around the outside.

The coal pockets are all waterproof, and there are no places where the coal can lodge, there being a complete system of hills and valleys. Mr. Pearson, the Consulting Engineer for the company, and Mr. Starrett, the Chief Engineer, have both had a good deal of experience in coal-pocket construction, and are, therefore, aware of the damage which can be done by the action of the coal on the iron.

As an instance, the coal pockets in the Kent Avenue power-house, in Brooklyn, may be mentioned. These pockets were lined with sheet iron, which corroded entirely through. The pocket at the Ninety-sixth Street power station was built of concrete, the spacing between the I-beams being filled with concrete and carried out 3 ins. beyond the face of the beams. Then the waterproofing—which was put in by a company whose formula, unfortunately, the speaker does not know—was applied, and it was found that it was of such a consistency that the dust of the coal knitted into it, and, so far, has not caused the least trouble.

The object of the belt conveyor is to take the ashes out when coal is not being hoisted. It runs usually during the night, but is sometimes run during the day, when the coal conveyor is not in operation. It was found to be too expensive to run the coal conveyor to take out the ashes alone, and, consequently, the belt conveyor was put in.

Mr. Boecklin. WERNER BOECKLIN, Jr., Assoc. M. Am. Soc. C. E.—The original plan was, as stated by the author, to handle the ashes by means of the returning coal conveyors, but a modification was found advisable, as the coal conveyors are not always running when it is necessary to remove the ashes, and, as the running of an 800-ft. conveyor, merely to transport them a distance of 75 ft. would not be economical, a Robins Conveying Belt was installed for the purpose.

This conveyor consists, essentially, of two parts—belt and idlers.

The belt is 16 ins. wide, reinforced along its middle by a coating of rubber $\frac{3}{16}$ in. thick to resist wear. The upper idlers, supporting the belt and its load, are made up of three 5-in. pulleys, two of which are set at an angle of 35° to the horizontal, thus troughing the belt and materially increasing its capacity. At the head end of this conveyor a circular brush, in contact with the return belt, is operated from the head shaft and throws off any ashes which may adhere to the belt after passing the head pulley. Mr. Boecklin.

Ashes are brought by means of small cars from hoppers under the boilers and dumped on the floor at the east end of building, and from here they are shoveled by hand into a long horizontal hopper delivering into a bucket conveyor. This conveyor rises to the level of the bridge, and, running horizontally, delivers upon the belt.

J. D. KENT, Esq.—Two engines are used to drive the coal conveyors, and they are between 15 and 20 H.-P., but the speaker does not think they have yet been carded. The smaller engine, when running the belt conveyor, exerts about 6 H.-P. The wet ashes, as they come from the ash pan, do not cause any trouble, but the soot, taken from the back of the boilers, sticks or cakes on the belt and has to be cleaned off. The large buckets are affected in the same way. Mr. Kent.

L. G. MONTONY, Assoc. M. Am. Soc. C. E. (by letter).—Mr. Averill expresses the hope that more details of the coal-pocket will be incorporated in the final discussion, but there does not seem to be much more detail to be described, unless the stress diagrams are submitted, and this seems hardly worth while. The point regarding the avoidance of dead spaces where the coal might lodge has been answered by Mr. Low. The cross-section of the pocket shows the bottom to be self-draining in that direction, while the longitudinal section indicates a horizontal bottom; but this is due to the fact that the section was taken on the center line of the boiler-house and not through the coal-chute throats. Between these, the bottom was lifted up in a series of concrete ridges so that the coal would slide clear in one direction if not in the other. Mr. Montony.

It might be well to state that at one time it was proposed to place a water-pipe around the top edge of the coal-pocket, with numerous hose connections, so that the pocket might be flooded at short notice. The writer does not know whether this is still contemplated, has been done, or has been given up.

The writer is very much obliged to Mr. Carr for correcting any misstatements in reference to the proportions of the concrete used, and regarding the sheet piling. The statement in the paper that "the former (Portland cement) was used in the foundation concrete and the latter (Rosendale cement) above Elevation + 0" should have been "the former was used in the foundation concrete and the latter in the building walls, floors, etc., above Elevation + 5."

Mr. Montony. There was no intention of implying any doubt as to the nature of the earth at the site, down to such a depth as to make piling the only feasible foundation. If there had not been a sufficient number of borings down into the blue clay he would hardly have tried to give as much detail as he did in regard to the various strata and their apparent levelness. While the reports indicated that one boring was carried down to —123 ft. and met a stony or rocky resistance, the writer does not believe this to be at all conclusive evidence that bed-rock could have been found at that level, as the reports indicated that the other borings were not carried much below — 80 ft.

As the conveyors have been put in operation and certain changes made in the proposed method of handling the ashes since the writer has seen the plant, he does not feel qualified to join in the discussion of that feature.